

Basic Hearing and Echolocation Mechanisms of Marine Mammals: Measured Auditory Evoked Potential and Behavioral Experiments FY 2007

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LONG-TERM GOALS

Broaden the baseline of hearing measures of marine mammals by increasing the number of animals and species measured. The effects of sound on wild populations of animals can best be determined if baseline hearing measures are known.

Improve the measurement of marine mammal hearing by developing and refining hearing procedures particularly those that will rapidly measure the hearing of stranded and temporarily caught animals.

Comparatively examine the basic hearing mechanisms of marine mammal species.

Compare the auditory evoked potential and behavior psychophysical methods for examining hearing in odontocetes.

Examine the effects of loud sound on dolphin hearing and temporary threshold shifts – particularly those frequencies used in the midfrequency sonars.

Develop an understanding of the basic processes of odontocete echolocation.

Develop and refine the measurement of hearing during echolocation particularly the hearing of the outgoing signals and the echoes from nearby and distant targets.

Examine automatic gain control mechanisms in odontocete echolocation.

Develop an understanding of the basic processes used by odontocetes to actively discriminate fine differences in echolocation targets and to model those processes for use in the development of improved sonars.

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OBJECTIVES

Marine Mammal sensory systems have evolved to effectively use acoustic energy in the oceans. My objectives are to develop a basic understanding of hearing and echolocation so that knowledge can then be applied to the solution of practical problems as they arise. The most basic hearing measurement is the audiogram which is a series of thresholds across frequencies. Of the 85 species of cetaceans we now have audiograms on 14 species. Audiograms on additional cetacean, and other marine mammal, species may be obtained from stranded animals, from animals in captive display situations, and from catch and release scenarios. We intend to obtain as many valid audiograms as possible as we seek new opportunities in new situations. Other hearing measures such as directionality of hearing are also very important and little is known on most marine mammals. These measures will also be obtained whenever possible.

Most of our initial audiometric work measured hearing using behavioral responses (Nachtigall et al, 2000). Measures of auditory evoked potentials (AEP) produce the benefit of being obtained rapidly without requiring captivity or lengthy training. Our recent work (Yuen et al, 2005) shows that the two procedures, while not producing exactly the same results, are certainly comparable. So, we intend to continue using AEP measures to measure the hearing of new species and to continue to measure hearing in other situations.

Our initial work on temporary threshold shifts (Nachtigall et al 2003, 2004) with exposures up to 50 minutes combined with shorter term exposures led to an equal energy hypothesis in which it was assumed that the amount of TTS was dependent on the amount of energy received relatively independent of the time of exposure. An objective of our recent work (Mooney et al, 2006) has been to examine whether the equal energy hypothesis is valid for short exposure times.

While much was known about outgoing dolphin echolocation signals, little was known about what animals heard while they echolocated (Supin et al. 2003, 2004, 2005) until we developed a procedure to measure AEPs during active echolocation experiments. Our current objective is to examine the automatic gain control of hearing during echolocation with targets present and absent.

APPROACH

The ability to obtain hearing data on new species requires opportunistic motivated action. I have a permit from the NMFS to test the hearing of stranded animals and keep in touch with the stranding networks in the US to keep opportunities for testing stranded animals available. Animals in public display facilities occasionally become available for hearing examination especially if the audiometric tests are conducted for short periods of time like those for AEP measures. The AEP measures can also be used on boats so that temporarily caught animals can be tested. All of these approaches allow us to increase the species and the number of animals tested. We work closely with Alexander Ya. Supin from the Russian Academy of Sciences to test the hearing of new species of animals, especially those that require a new technique or adaptations to new procedures.

We primarily use the envelope following response auditory evoked potential approach in which we present amplitude modulated sounds to the animals and monitor the brain wave patterns in response to the amplitude modulation rate. While that works well for cetaceans, we also use individual tone pip AEPs for those marine mammals, like the polar bear, that are not as prone to rapidly follow amplitude

modulated stimuli. Our work with the polar bear is conducted with the staff of Kolmården Djurpark in Sweden, particularly Mats Amundin.

Temporary threshold shift work is primarily accomplished by testing the hearing of the dolphin, exposing it to sound, then retesting hearing immediately using evoked potential measures. T. Aran Mooney, a doctoral candidate, has been the principal person measuring TTS for the past couple of years. The next objective of this work is to present intermittent sounds produced by navy midfrequency sonars to see whether the sonars produce the predicted amount of TTS.

Hearing is examined during echolocation by measuring the hearing when the outgoing pulse is produced and when the echo is returned by measuring the brain response timed from the outgoing pulse. Target strength is varied by changing the distance and target strength of the targets. The animal is required to echolocate and report the presence or absence of the target and AEP recordings of its hearing while doing that are the important dependent variable.

WORK COMPLETED

Measured the audiograms of three polar bears.

Tested TTS for short exposures and compared them to long exposures.

Measured the hearing of the false killer whale during echolocation for its own signals as well as those presented directly in front of it.

Compared the hearing during echolocation of the false killer whale to hearing its own signals and echoes.

Examined whether or not there were automatic gain control mechanisms in the hearing of the false killer whale during echolocation.

RESULTS

No bear had previously been tested for hearing measurements. The bears heard very well and had a much broader frequency range than anticipated – from 4 to over 20 kHz. The data indicate anyone dealing in the arctic should be aware of the sensitive hearing of the marine polar bear.

TTS was found not to follow the Equal Energy Hypothesis. Short exposures took more energy to produce shift than longer exposures.

Found that an echolocating False Killer Whale hears its own outgoing signals 40 dB down from the same level signal presented directly in front of it (see Fig 1). The animal has protection from its own loud outgoing signals.

Found that an echolocating False Killer Whale controls its own hearing during echolocation to ‘lock on’ to the echo from the target and adjusts its hearing to maximize the hearing of that echo. The animal adjusts its hearing during echolocation.

Found that there is an automatic gain control in the hearing system of an echolocating false killer whale. There are at least three mechanisms of automatic gain control in odontocete echolocation – echolocation and hearing are a very dynamic process.

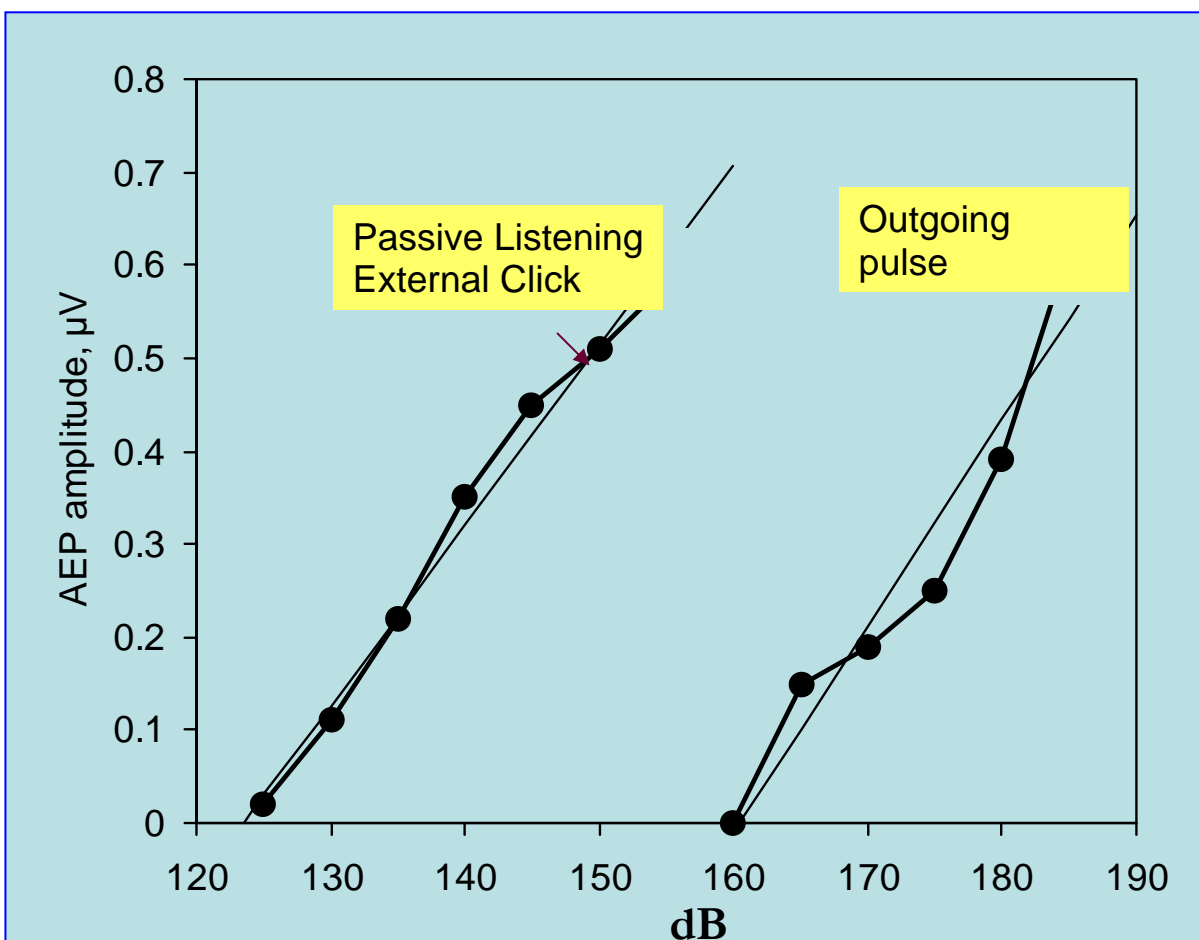


Figure 1. The echolocating whale hears its own echolocation clicks about 40-45 dB down from the same level clicks presented directly in front of it.

IMPACT/APPLICATIONS

At least some delphinids hear very well up to 180 kHz, an area where many high frequency sonars operate.

We still do not know the hearing range and sensitivity of the mysticete whales. We presume they hear low frequencies, but perhaps like the polar bears, they hear much higher frequencies than we assume. If that is true, it is reasonable to be concerned about the effects of sound on mysticete whales. The mysticete whale hearing issue remains and important one to be resolved.

Polar bears hear well from 4 to over 20 kHz. Those operating in the polar bear areas in the arctic should be concerned and aware.

The total energy likely to produce TTS is greater for short sounds than it is for longer sounds. Shorter exposures of an equal amount of energy are less likely to produce temporary hearing loss in dolphins.

Odontocete echolocation is a very dynamic process in which the hearing of the animal is changing to meet the situation encountered in the environment and the targets. There is no other auditory system that is controlled in this manner. Most control of hearing is by stapedial reflex in response to loud noise. In this echolocation hearing control, sensitivity is controlled by optimizing the hearing of the target echoes. The animal also has a built in protection for its own loud outgoing pulses – up to 40 dB of built in protection.

TRANSITIONS

The SPAWARSYSCEN in San Diego California uses the basic procedure that we developed to test dolphin hearing with auditory evoked potentials in research and also to measure the hearing of Navy systems animals

RELATED PROJECTS

In a related project, funded via the University of Southern Denmark with permits from the Icelandic government, we examined the hearing of the white beaked dolphin. It was believed that white-beaked dolphins heard up to 250 kHz. While they did not hear that high, we found that they did hear up to 180 kHz by examining their hearing in a catch and release program off of a fishing boat in Icelandic waters. This new technique demonstrated that animals could be successfully caught, their hearing measured, and then successfully released within 90 minutes time with no harm to the animals.

In a similar related project, funded by the Joint Industry Program, we had the opportunity to attempt to catch a wild minke whale to measure its hearing. While we were not successful, this was the first attempt to capture a mysticete whale to measure its hearing. No large mysticete whale has been audiometrically examined.

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